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Body Dynamics and Muscle Activity during Chi Running

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Body Dynamics and Muscle Activity during Chi Running

by

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Dedication

In memory of my best friend Lindsey John.

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The University of Texas at Austin, 2010

Supervisor: Lawrence Abraham

This study compared the center of mass behavior and muscle activation patterns during Chi running and normal running. The study included 10 participants, both male and female, who were recreational runners training at least 5 days a week. Thirty-second trials were collected continuously on a treadmill in the University of Texas Non-linear Biodynamics Laboratory. The variables being examined were the COM vertical position and COM acceleration in the A/P direction, the angle of lean, the gravitational moment about the ankle, and EMG amplitude and duration from four leg muscles. Although no significant differences were found between the two conditions for any of the dependent measures, there was a visible change in running form. A larger number of participants or a different set of dependent measures may be required to observe statistically significant differences.

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Chapter 1: Introduction and Background Information
1.1 Introduction

Running is one of the most common forms of recreational activity in the world. More than 24 million people in the United States annually participate in running. Of these runners, 60 percent or more will have an injury that causes them to stop running for some amount of time (Dryer and Dryer, 2004). Over the past few years, much running research has been focused on the causes and prevention of injuries, and elaborations of previous studies of running kinematics and kinetics. Studies detailing foot strike patterns, muscle activity, ground reaction forces, and influence of a variety of orthodics have all been examined and re-examined. The ideal outcome of these studies would be to generate a biomechanical model of efficient running that can be applied to every runner. However we are far from that goal. Even with the vast amount of information already known, running is a very complex task to perform and to study. A large part of the analysis complexity stems from individual differences inherent in each participant. There appear to be very few similarities across groups of runners, and it seems that almost every runner has a unique "most efficient" biomechanical model. This situation leaves biomechanists with the question; Is there a way to run that can reduce injuries and be custom tailored to individuals? Many people have tried to answer this question scientifically and none have succeeded. There are others who claim to have "answered" this question and had success with their techniques, but they have not yet been validated with experimental data. This study was designed to examine scientifically one example.

1.2 Chi Running Form

The ongoing debate over proper running mechanics and the popularity of the sport have led to the development of a number of different running forms, largely involving variation of the different aspects of stride mechanics intended to manage the internal and/or external forces acting on the body while running in an effort to provide the desired propulsion while minimizing the loads that can cause injuries. Each time a runner's foot hits the ground they experience forces 3-5 times their body weight (BW) (Nigg,1993). Many running forms have attempted to change this significant loading on the body. Chi Running, the Pose Method, one portion of the Alexander Technique, and now the emergence of barefoot running are examples of these different running forms/styles. Recently, Jungers (2010) reported positive biomechanical effects of barefoot running. This study highlighted the importance of the reduction of the impact transient while running. Chi Running and the Pose technique both require the same type of foot placement, signifying this idea has been around for quite some time. Pose Running, created by Nicholas Romanov in 1997, has been clinically tested but Chi Running, one of the newer and most popular of the mentioned techniques, has no quantitative data to support its theories. This study was conducted to quantify how Chi running affects the mechanics of running.

Figure 1: Chi running "lean"

Danny Dryer, a renowned coach and masters runner, created the Chi running method (Dryer & Dryer, 2004). The Chi running form encompasses ideas of the ancient practice of Tai-Chi, and Chi runners are instructed to harness the power within the core of the body to run more efficiently. Chi runners learn to create a whole body lean from the ankles (Figure 1). Dryer claims that this lean allows gravity to become the “gas pedal” and allows the runner to do “less work.” The idea of gravity propelling a runner forward is different from the traditionally understood role of gravity in running. In conventional thinking, gravity’s role in running is a downward force opposed by an upward normal force exerted by the ground on a runner (Chang et al, 1999). The proposed new understanding of the role of gravity is the premise of the Chi technique. Chi running requires the runner to focus on lifting the legs rather than pushing off the ground, to land on the mid-foot rather than the heel, and to demonstrate “proper” postural alignment and relaxation of the legs. The theoretical principles of the technique challenge ideas found in previous kinematic and kinetic running studies, yet open the door for a new avenue of research to determine what exactly makes Chi running a beneficial form of running. Qualitative research examining Chi running exists (Cucuzzella, 2008), but the technique has yet to be quantitatively examined. If Chi runners are effectively able to incorporate the proposed principles, the mechanics of a Chi runner’s stride should be noticeably different from those of a non-Chi runner. The purpose of this study was to determine the underlying principles of Chi running by studying the position and path of the center of mass and to determine the levels of activation used in four main muscles of the legs during Chi running compared to non-Chi running.

1.3 Role of Gravity and Center of Mass

To discuss whether Chi running affects the center of mass trajectory, there must be agreement on the concept of the center of mass. The center of mass is the theoretical point where all moments about the body sum to zero when no external forces are applied. The location of the COM at any point in time with respect to the body depends on the shape or configuration of the body at that time. On average, in the anatomical position the COM is located around the middle of the abdomen. Biomechanically, to assess the location of the center of mass, one must calculate each individual body segment's center of mass, and then compute the weighted sum of these segmental centers of mass to generate a single theoretical point that can then be followed throughout the movement. The center of mass trajectory during running has been demonstrated most graphically in research on the spring-mass model (McMahon, 1987). This model shows the COM to be at its lowest point while running when the leg is fully compressed and loaded in stance, and at its highest point during mid-flight.

Tracking the path of the center of mass is important in examining Chi running to determine if a runner is able to effectively control the COM. If a runner can control the COM as prescribed, then it is conceivable that the whole body lean will result in gravitationally-induced forward falling, which will have a propulsive component. Chi running also prescribes a softer foot impact, which should reduce the typical braking component of foot impact and should subsequently reduce the propulsive force required to maintain running speed. In this case the center of mass trajectory will be more linear than in normal running. This would mean a runners' COM should have reduced vertical translation while running, allowing running to be defined as the primarily smooth horizontal displacement of the COM (Romanov & Fletcher, 2007).

Chi runners are described by Dryer as having a more linear trajectory of the COM than a normal runner. However, if gravity is in fact providing a propelling force, it must not be accelerating the runner throughout the run but rather gravity's horizontal propulsive force must be matched largely by some horizontal braking force, allowing the runner to maintain a more constant velocity. To the extent this happens,a Chi stride would decrease the alternation in horizontal acceleration of the COM compared to a non-Chi stride.

1.4 Purpose of Study

The aim of the present study was to determine if Chi running is different from the previously described kinematics and kinetics of running. Specifically, the center of mass (COM) behavior and the lower leg muscle activation patterns were examined to assess the effect of Chi running on running mechanics. Since the Chi method emphasizes that gravity can assist a runner, this study attempted to determine the role of gravity in Chi running by looking at lean and the gravitational moment about the COM. Chi running has many testimonials from numerous runners claiming that it has improved their running greatly. The purpose of this study was to investigate the stride manipulations Chi runners are actually making when adopting this running form. This should help explain how the techinque could be advantageous.

1.5 Hypotheses:

After studying the existing literature on running and mechanics, the following hypotheses were created to guide determination of the advantages and underlying mechanics of Chi Running.

H_1: The vertical variance of the location of the center of mass in runners using the Chi method will be smaller then runners using a normal stride.

H_2: Runners using the Chi method will have less alternation in horizontal changes in velocity of the COM.

H_3: A runner using the Chi method will create a larger "lean" then a runner using a normal stride.

H_4: The average gravitational moment about the ankle of a Chi runner during stance will be larger than that of a non-Chi runner.

H_5: There will be no difference in levels of amplitude of the rectus femoris, biceps femorus, medial gastrocnemius, and the tibialis anterior between runners using the Chi method and runners not using the Chi method.

H_6: The muscle activation sequences (onset and offset time) for runners using the Chi method will be no difference then runners using a non-Chi method during stance or swing phase of the gait cycle.

1.6 Background

Biomechanical analysis of running

Many biomechanists have studied the mechanics of running, examining both kinematic and kinetic variables in detail. During running locomotion general patterns have been described for the COM kinematics and muscular activity. Since no research literature exists on Chi running, these general patterns provided the starting point for analyzing the mechanics involved in Chi running. Results of previous studies, which manipulated different aspects of foot placement, knee flexion angles, trunk lean, fluctuating inertial and gravitational components, and varied surfaces, were used as a basis for examining what the Chi Running form teaches.

The Chi method focuses on making running “effortless and injury free”. Chi running teachers instruct people to utilize their core strength during running, a principle based on the ancient practice Tai-Chi. Chi runners learn to create a lean from the ankles throughout the entire body (Figure 1). According to the technique, it is this lean that allows gravity to become the “gas pedal,” making less work for the runner. This idea of gravity propelling a runner forward is largely different from the conclusion of previous running studies. Chi is marketed as a techinque that reduces effort and injury.

Chi Running requires the runner to do the following four things: 1) lift the legs rather than push off the ground, 2) land on the mid-foot rather than the heel, 3) demonstrate proper postural alignment (letting the skeleton hold the body weight) and 4) relax the legs. These 4 principles of the technique challenge ideas found in previous kinematic and kinetic studies of running. Running is thought to have an active pushoff phase, where several muscles, including the rectus femoris (RF) and gastrocnemius (GS) are both active. Toe off is typically when the COM is at its peak upward vertical velocity. This occurs before 50% of the gait cycle (Novacheck). Also, midfoot strikes rather then heel strikes show a decrease in initial ground reaction force (GRF) (Cavanaugh). The third and fourth principles would indicate that we should see less than typical muscle electromyographic (EMG) amplitude, since the proponents of the technique claim it involves less intense effort..

In previous studies, gravity’s role in running was understood to be a downward force in opposition to a normal force exerted upward on the runner by the ground (Chang et al, 1999). A runner must exert a vertical force on the ground that is equal and opposite to the runner's weight to keep from falling, and a larger force to propel the body upward for the flight phase.. When gravity is examined separately from inertia, it has been noted that gravity can affect horizontal braking and accelerating impulses as well as the vertical impulses. (Chang 1999). However, no research found to date clearly identifies gravity as a propulsive force during running. The Chi technique is claimed to be based on the principles of physics - appearing to use the assumption that Chi running turns the body into a single rigid lever. The lean can then cause gravity to create a torque on the lever and cause forward rotation to occur. Many of the hypotheses of this study were designed to investigate the actual role of gravity during Chi Running, since this is the most unique characteristic of the technique and also one that contradicts the existing literature.

During running, the COM has both vertical and horizontal trajectory components, both of which are affected by gravity. The COM trajectory in the vertical direction has a wave-like pattern with the peak of the COM during the flight phase and the lowest point during statnce when the knee is at its maximum flexion angle. The COM vertical fluctuations are only a few cm different from peak hieght to the lowest point, however a definate osciilation pattern is involved. The horizontal force acting on the body (and hence the COM) during the first half of stance is negative and causes the runner to brake as the COM loses kinetic energy and gains strain potential energy. The second half of stance involves positive acceleration and propels the runner forward and upward. In this phase of stance the COM then loses strain potential energy and gains kinetic energy. In Chi running, the COM trajectory should have smaller excursions in the vertical direction and steadier horizontal velocity compared to regular runners. This would be supportive of Dryer's claim that Chi mechanics cause runners to have more efficient control of their COM.

1.7 Muscle Activation and involvement during running

While running, muscle activation changes for a variety of reasons. Previously studied conditions which affect EMG activation patterns during running include reduced gravity, foot placement, and altered GRF situations (Wakeling, Pascual &Nigg 2002, Romanov & Fletcher 2007). In this study four of the major muscles of the leg were selected for EMG data collection; tibialis anterior, medial gastrocnemious, rectus femoris and biceps femoris. The selected muscles were chosen according to previous reports on muscle activation during running. The gluteus maximus, which has been suggested to experience important differences in activation with Chi running (Smith, personal communication, 2010) was not chosen because it is extremely hard to palpate to achieve proper surface electrode placement and because placing electrodes on the skin over it can often make participants feel uncomfortable.

Chi Running teachers instruct runners to lift their legs (instead of pushing off the ground) at toe off and to relax the legs throughout the swing phase. With this guiding principle, it is possible that decreases in muscle activation levels would exist between Chi and non Chi running. However, since lifting the legs will ultimately still require muscle activation, it was hypothesized that the Chi method would show no difference in levels of activation and frequency of the rectus femoris, biceps femoris, medial gastrocnemius, and the tibialis anterior compared to a regular running pattern. Also because Chi running still involves the typical gait cycle pattern (initial contact, stance, toe-off, swing, and initial contact), the sequence of activation patterns for Chi trials was hypothesized to show no difference compared to the non-Chi groups during stance and swing phases of the gait cycle. Muscle activation levels do increase with speed. This study was designed so the participants would run at a steady pace. Although their cadence could change throughout the trial, overall speed was regulated by the speed of the treadmill belt (Kyrolainen, Avela, Komi 2004). A null hypothesis was chosen with regard to hypotheses five and six beacuse the proposed changes in mechanics would not clearly alter the muscle activation enough to create significant differences.

1.8 Kinetics of running

Chi running focuses primarily on managing one external force during running, gravity. According to the literature the external forces that affect a runner are both gravity and internal inertial forces. (Chang, Huang, Hamerski, Kram 1999). Chang et al. varied the gravitational and inertial effects on running to determine what changes occurred under these new conditions. In reduced gravity conditions, participants showed decreased ground reaction forces and appeared to have decreased the muscle activation in specific muscles, however in normal gravity conditions gravity is considered to be a vertical force that a runner must oppose. The main horizontal force involved in running is inertia and it is closely dependent on the mass of the runner. According to Chi running, gravity becomes the motivating force rather then a force in opposition to the body (Dryer, 2004). Dryer explains that gravity is doing the work – supporting the weight of the body and moving the body forward. This is different from the role of gravity described by Chang et al. Another force that is examined during running is the ground reaction force (GRF), which is the force the ground exerts to counteract gravity. GRF can be decreased by adapting a mid-foot strike. With a “forefoot” strike (any foot strike that doesn't involve the heel), the runner eliminates all or most of the initial "braking force" also associated with the impact transient. (Fredrick, Hagy 1986). Since Chi running utilizes a mid- foot strike with the foot underneath the body, it was important to look at the GRF in a mid-foot striker verses a heel striker. This would indicate whether Chi Running has a lesser or non-existent impact transient. However this study did not include the study of ground reaction forces, primarily because the necessary equipment was not available for simultaneously studying kinematics and GRF.

Other studies have analyzed the effect of changing the gravitational component, revealing that the internal force of propulsion decreases due to changes in gravity (Cavanaugh & LaFortune 1979, Munro& Miller 1987). According to this study, gravity might aid the runner in reducing this internal propulsive force by one of two ways. The first could be to reduce the normal force that the body exerts and the second could be that gravity can aid in accelerating the body forward. According to Cavanaugh et al (1980), for steady state running, the A-P velocity change during contact should be zero. This means that the braking forces accounting for loss of velocity should be equal to the propulsive forces accounting for the gain of velocity yielding a zero net acceleration. The question asked in this study was whether a Chi runner who uses gravity to generate the forward propulsion, has an equal or larger braking force compared with steady state running.

The primary kinetic forces involved in running are gravity, GRF, and inertia. In most running studies, the main force studied is the GRF and how it changes with speed and foot position. Since Chi running uses a midfoot strike rather than a heel strike, these studies are relevant. Also, Chi running considers gravity to be the motivating force, therefore Chang et al explains the original role of gravity and Dryer's book argues that this role changes with Chi running. The study by Cavanaugh was the first compilation of GRFs in running.

These external forces are important because identifying their role helps to determine the gravitational component in Chi running.

1.9 Kinematics of running

The mechanics of running are often explained by kinematic data. Since position data can determine where the subject is in space and how the segments are moving in respect to each other, it is very important when studying gait. Chi running theoretically changes the mechanics of running and this can be shown through kinematic data.

During running, the center of mass trajectory can be studied to determine the position of the body during running. In normal running, the COM has a wave like pattern as indicated by the mass-spring model. With the adoption of a Chi running stride, the COM trajectory should be more linear since gravity's effect should be constant (Blickhan 1989, Novacheck 1998, Geyer et al 2006, Lee and Farley, 1998). Although not addressed within this study, additional energy costs are created by controlling the COM movement (Romanov, Gordon, Ferris and Kuo 2009). Careful research could determine if controlling the COM costs more energy. If it does, additional questions would arise about the proposed advantage and how a runner compensates for the energy spent to control it? Foot position during stance also affects body dynamics. A mid-foot strike reduces the amount of knee extension during running (Lebiedowska, Wente and Dufour 2009, Romanov 2004). With reduced knee flexion, the knee flexor muscles should be less active and might reduce work done by the body. As stated earlier, utilizing a forefoot strike decreases the GRF. This combined with less knee flexion could indicate that this way of running is easier on the body.

Definition of Terms

Center of Mass (COM): a theoretical point about which all moments sum to zero or the location about which the mass of the body is evenly distributed.

Chi running: A running form that requires the runner to (1) generate a lean from the ankles throughout the body, (2) demonstrate proper posture to support the weight of the body, (3) lift the legs instead of pushing off the ground at toe-off, and (4) to relax while running.

Non-Chi running: A runner's normal, non-manipulated stride.

Lean: Key principle in Chi running, measured from the COM to the base of support

GRF: Ground reaction force

RF: rectus femoris

BF: biceps femoris

GAS: gastrocnemius

TA: tibialis anterior

% Step cycle: defined from initial foot contact to the next occurring foot strike of the opposite foot. (I.e. right initial contact to left initial contact.)

% Gait cycle: defined from initial contact of one foot until the same foot contacts the ground again. The gait cycle is considered to be one full stride.

Chapter 2: Methods

Participants

Participants were ten male and female runners from the Austin Area. Five Chi runners and five non-Chi runners were recruited to participate. The runners were healthy with no current orthopedic limitations; they were screened prior to participation in the study. Subjects were required to be able to complete a thirty-minute run at a sub 9 minute/mile pace, although the running portion of the study did not take a full thirty minutes. The subjects were allowed to fully adapt to the treadmill surface and were allotted as much time as needed.

The lead researcher for this project obtained informed consent from each participant. Each individual was given an informed consent form, approved by the University of Texas at Austin department and University's institutional review board. The form indicated that the participants agreed to participate and understood what was being asked of them in this particular study as well as the risks and potential benefits. They were directed to read and asses this form prior to participation in the laboratory. The researcher explained all procedures and tasks that the participant was to complete. The participant read the consent form thoroughly and had the opportunity to ask any questions about the study, consent form or anything that remained unclear. The participant then signed two copies of the consent form, one for the researcher and one for their personal records. The researcher also signed both consent forms indicating that the participant and researcher were in agreement.

In order to maintain confidentiality, all participants were given a testing ID and names were not attached to specific data files. The record of the data is kept in a secure, locked location. Analysis of the data only included coded ID information. Researchers were the sole individuals who have access to the raw data. Dissemination of the data will describe group means; sample data displays did not include participant identifiers.

All participants in this study were from the greater Austin area and were recreational runners who run regularly. The age range for recruitment into this study was 20-45, and over 45 with permission of the participant's main physician. The participants were healthy with no current orthopedic limitations. There were two separate groups in this experiment. One group consisted of five participants experienced in using the Chi running method. These Chi runners had been trained by a certified Chi running instructor and had been practicing Chi running for a minimum of six months. Selected Chi participants were validated by the Chi running instructor and/or acquired with the instructors help. These participants completed running trials using a normal and again using a non-Chi method. These trials were randomized to ensure the participants maintained their Chi form during that portion of the data collection. The second group was the comparison group comprised five participants non-Chi runners, referred to as the control group. The mean age of the Chi group was 36 and the control group was 32.5. The total study population consisted of 5 males and 5 females. The Chi group consisted of 3 females and 2 males.

Participants were recruited in numerous ways. Flyers were hung in local running shops; an article was posted to a prominent running website based in Austin and also through the help of a Chi running coach, local running leaders. Many potential participants were interested in being part of the control group, but the Chi running population was much smaller than expected. There were many responses from local runners claiming they had read the Chi Running book, but they lacked any formalized training. These participants were not included in the study to ensure the validity of our experimental group.

Subjects		
	Chi	**Non-Chi**
Age	26-45	25-40
Height	1.52-1.82m	1.52 - 1.854m
Weight	51.25-83.45 kg	56.7-95.25kg
Gender	3F,2M	2F,3M

Table 1: Participant anthropometric data

Instrumentation

Motion Capture: A ten camera VICON motion analysis system was used to collect kinematic data. Fourteen mm reflective markers were placed on the subject. A full body 57 marker set including markers on the left and right side at the following locations was used: toe, ankle, heel, tibia, knee, thigh, ASIS, PSIS, C7, T9, sternoclavicular notch, sternum, right back, shoulder, elbow, wrist (A and B), finger, front head, back head. The figures below show a static DV image and the Vicon generated model.

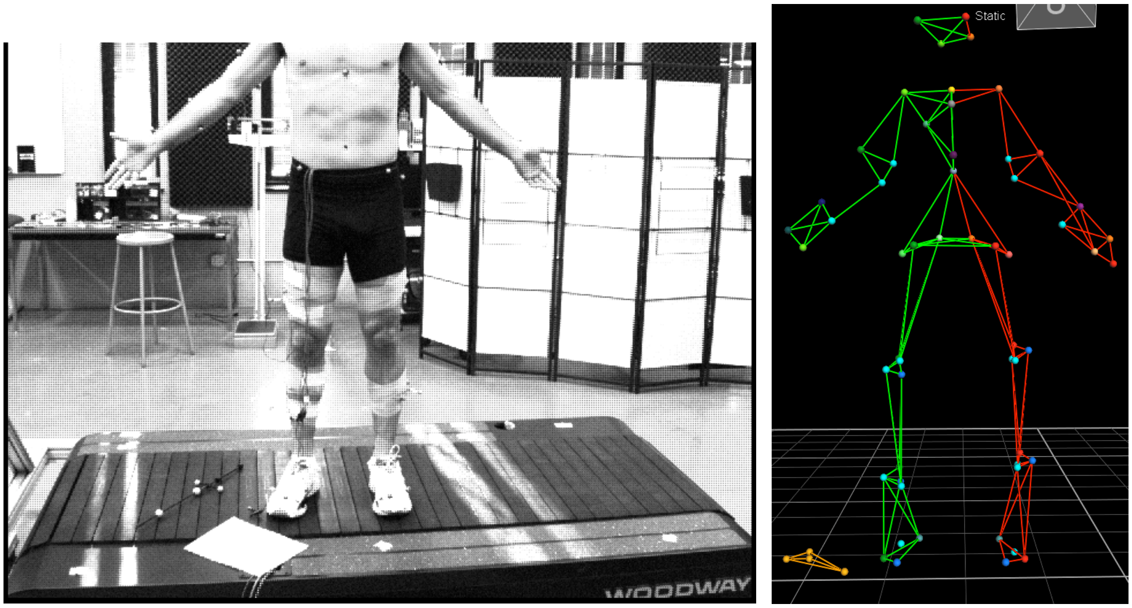

Figure 2 and 3: Participant with Vicon marker set and digitizing wand (left). Computer generated skeleton of the same participant.

Software:

C-Motion Visual 3D software was used to calculate the center of mass for each subject. To use this software, a digitizing wand was used to indicate the joints of the ankle, knee, pelvis, hip, shoulder and elbow. The joint marker digitization was completed in a specific order from the participants left to right. Once these digital points were recorded and identified by the experimenter, a model was generated from the specific participant's anthropometric data.

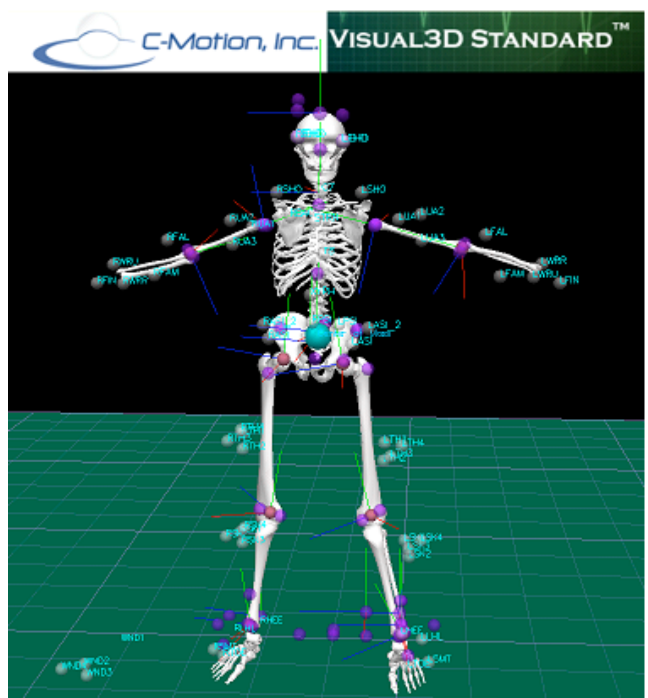

Figure 4: V3D generated model

The center of mass (COM) was then calculated and tracked through each dynamic trial in the A/P and vertical directions. Data were then exported into Matlab and processed.

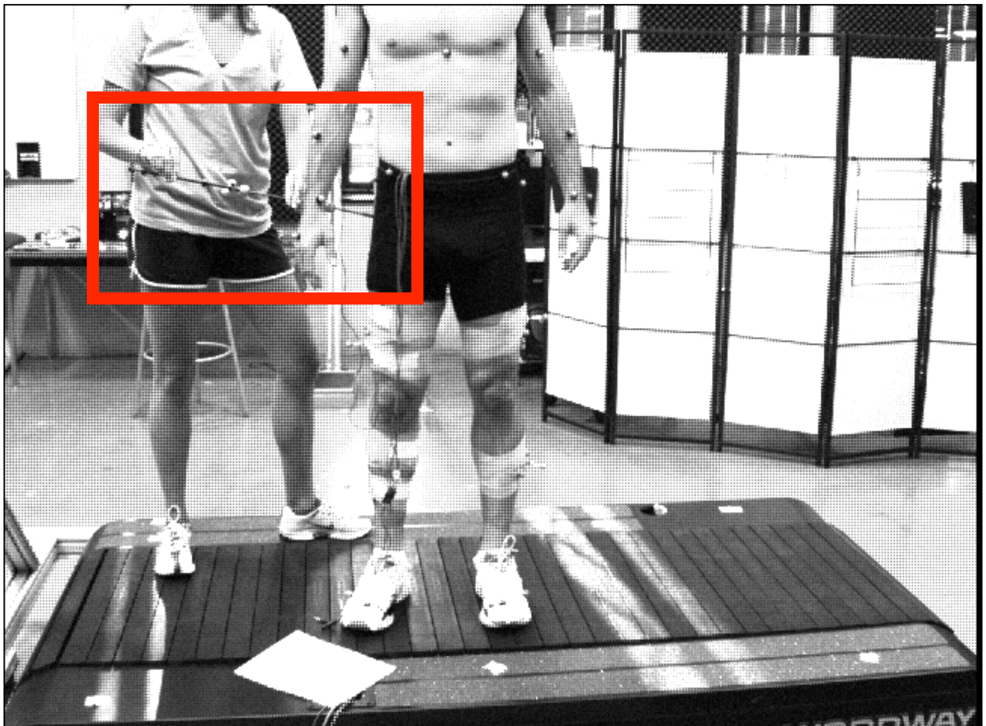

Figure 5: Experimenter and participant during digitizing wand trial. Experimenter is indicating the joints with the digitizing wand (indicated by red box).

Treadmill apparatus: A Woodway treadmill was used for data collection. Treadmill data collection has been widely studied and proven an efficient means of data collection. Kinematic data from treadmill studies has been found to

Figure 6: Woodway treadmill in the Non-Linear Biodynamics Lab at University of Texas.

properly demonstrate the same mechanics as that of overground running for the variables included in this particular study (Riley et al, 2007, Riley et al, 2008). This specific treadmill had no support bar, which allowed Chi runners to create their lean more efficiently than if a front bar had been in place. If a participant felt uncomfortable or unstable, a harness was provided to support the runner. Participants were allowed as much time as desired to adjust to the treadmill and were required to complete at least 5 minutes of walking or slow jogging before they began the actual experiment. Treadmill adaptation (3-5 minutes minimum) is important requirement to ensure the participants are not changing mechanics due to surface differences (Riley et al, 2008).

Data Analysis:

The center of mass (COM) was calculated by V3D code and a generated model containing anthropometric data. The COM displacement was calculated by determining the minimums of the trajectory and averaging each step, in each trial for every individual participant. A mean value was calculated for each group.

The angle of lean was calculated by extracting the left ankle marker data from the generated model. The ankle marker is a digitized point that is created by the experimenter and can be calculated throughout each dynamic trial. The angle was calculated using trigonometric functions and the distances in the A/P and vertical directions from the ankle to the center of mass. The distance was computed by calculating the absolute value of the differences in both the horizontal (y) and vertical (z) directions and computing the angle with respect to the vertical. The angles were then manipulated to examine the angle from the segment from the ankle to the COM with respect to the ground. The calculated angles were found only during stance because during the stance phase of the gait cycle is where the Chi runner creates and optimizes “lean.”

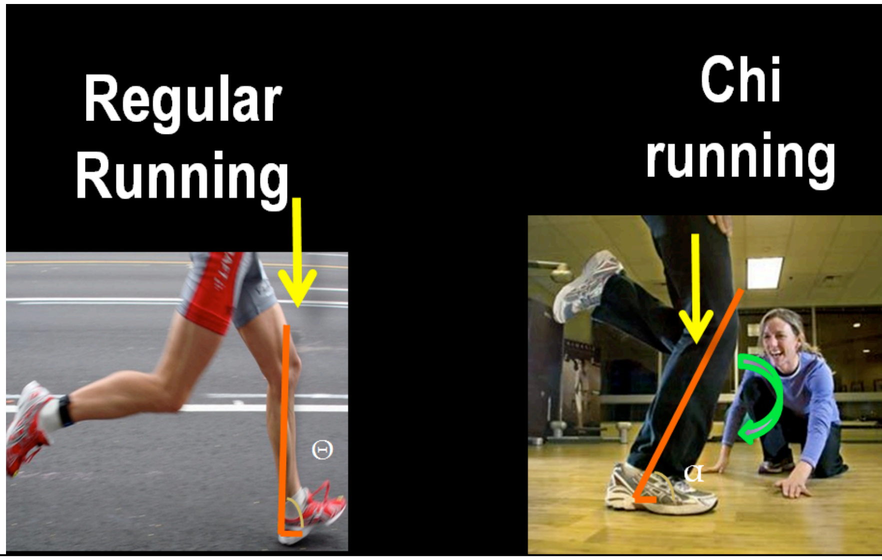

Figure 7 shows a heel-strike on a non-Chi runner (left) and a forefoot strike of a Chi runner (right). The location of the angle measurement is shown.

The gravitational moment calculation consisted of taking the product of the A/P distance from the COM to the ankle and the subject’s weight. Since force plates were not available, the second best option was to determine the moment caused by gravity at the time when the runner was in single leg stance as indicated by the ankle marker.

To measure muscle activity, EMG data was collected with Delsys bipolar surface electrodes. The electrodes were placed on the skin over the rectus femoris, biceps femoris, medial gastrocnemius, and tibialis anterior. The surface electrodes were placed with adhesive directly on the shaved and cleaned skin. The RMS value was calculated for each muscle and normalized to the percent gait cycle. The RMS values of the Chi group in both conditions, Chi and non-Chi, were compared to determine differences of muscle activation and duration.

Procedures

This experiment took 1.5-3 hours in its entirety for each person, depending on the participant's ability to adapt to the treadmill surface and their ability to perform Chi running form (unless in the control group). This was a non-invasive study. Each participant read and signed the consent from indicating they were free to stop at any point in time from discomfort, fatigue, or any other reason.

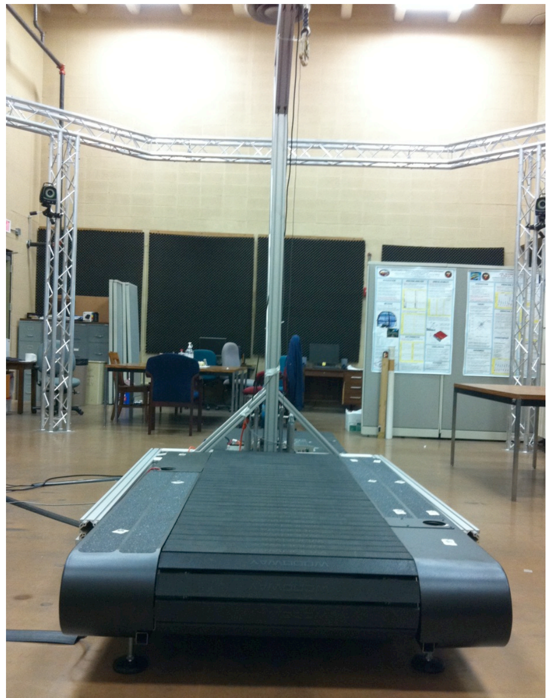

Figure 8: View of the treadmill belt

Test administration

After signing the required paperwork, the participant was weighed, and their height was recorded. Then the participant was prepped for marker and electrode placement (alcohol swap/razor). Kinematic markers and electrodes were attached to the participant's skin. Muscles placement was verified with palpation during individual muscle tasks, then maximal voluntary contraction's (MVC) were collected for 2 seconds for each muscle. The participant then acclimated to running on the treadmill. Data collection then began with a continuous run with 30 second trials collected by the investigator The participant stopped once 10 trials of Chi running and non Chi running were collected. If subject was Chi running, they were asked to perform their best attempt at "non-chi" running. The control group has only performed 10 trials of regular running. After data collection was finished, the markers were removed and participant's skin was cleaned.

Experimental design:

This study had a quasi-experimental design, in which the dependent variables were the vertical and horizontal COM kinematics, lean, gravitational moment and EMG amplitude, and activation pattern. This study used a within subjects design to compare the Chi runners during both conditions (Chi running and non-Chi running) and a between subjects design to compare the Chi runners with the non-Chi runners. COM trajectories (vertical and A/P), lean, moment and EMG pattern, were each represented by the mean and SD of the mean. Independent sample and paired sample t test were calculated for each dependent measure.

Chapter 3: Results

3.1: Kinematics

3.1a: Vertical displacement of the COM

The center of mass location was generated using Visual 3D software and anthropometric measurements taken for each individual participant. After the COM position at each point in time was calculated, percent gait cycle was calculated by determining the minimum values of the center of mass position. The gait cycle for this variable was calculated from mid-stance to mid-stance (i.e.: one step).The center of mass trajectory in the vertical (Z) direction for Chi runners was lower than for normal runners on average but not significantly (p=0.2). This difference was hypothesized to exist based on the mechanics of Chi running, specifically the fact that Chi runners are instructed to attempt to run with as little vertical excursion as possible.

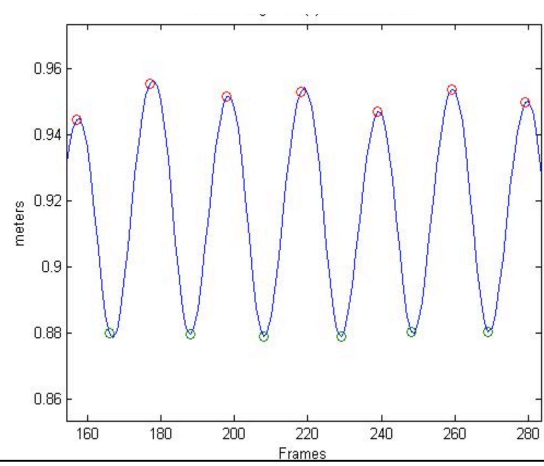

Figure 9: demonstrates how the COM maximum and minimums were found.

The start of the gait cycle was defined as the middle of the stance phase, when the foot is in contact with the ground. The stance phase is where the leg is fully flexed and the COM is at its lowest

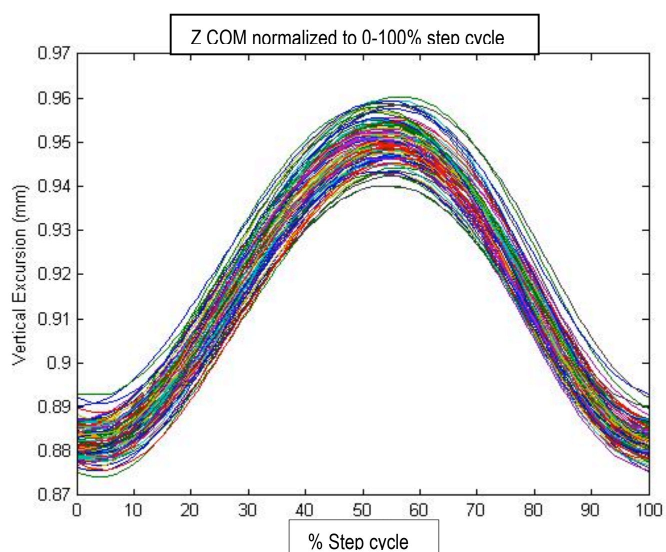

Figure 10: Vertical displacement normalized to percent of step

point during the entire gait cycle. Since the participants had varying height, the COM vertical displacement measures were normalized to body height in order to compare the overall displacement during Chi and non- Chi running.

The vertical displacement was a small value to begin with; therefore the standard deviations seem relatively large in comparison to the actual displacement values. Data were collected in 30 second trials, 10 trials per participant and condition. Once the data had been normalized to percent gait cycle, the average of the strides were taken, roughly about 50 gait cycles per trial.

Once the trial averages were calculated, the overall average of the ten trials was calculated for each participant and then group averages were calculated. The Chi group did in fact show a smaller deviation of the COM in both conditions (Chi and Non Chi). The Chi runners had a vertical displacement of 0.04242 meters compared to the non-Chi runners 0.04708 meters displacement. Chi runners, when attempting to run "non-Chi", still had a smaller value (0.04167m) then the non-Chi group (p= 0.377). The group by group comparison is shown in figure nine.

Table 2: Vertical COM displacement values

Group	**Z Displacement**
Chi	0.04242 m
Chi (non-chi)	0.04167 m
Non-Chi	0.04708 m

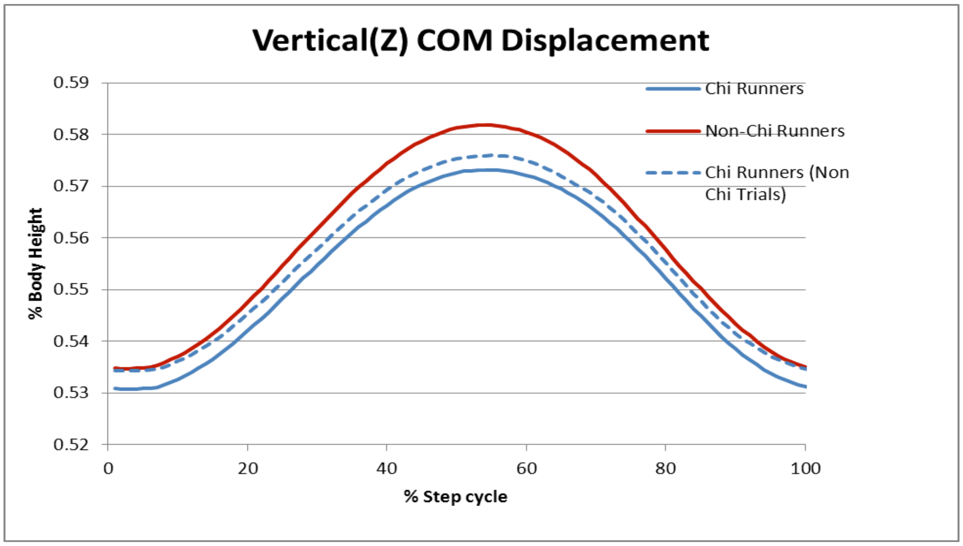

Figure 11: COM trajectory in the vertical (z) direction for Chi runners in both conditions and the non-chi

3.1b: A/P acceleration of the COM

The second hypothesis related to the COM examined the change in velocity in the anterior/posterior direction. The aim of this variable was to determine if the forward (propulsion) and backwards (braking) acceleration of the COM for Chi runners were greater than or less than those of non-Chi runners. Since each runner was running at a steady pace in both conditions, a zero net acceleration was anticipated and the propulsive and braking impulses for each runner cancel out over time. However the magnitude of these paired accelerations could vary across individuals and conditions.

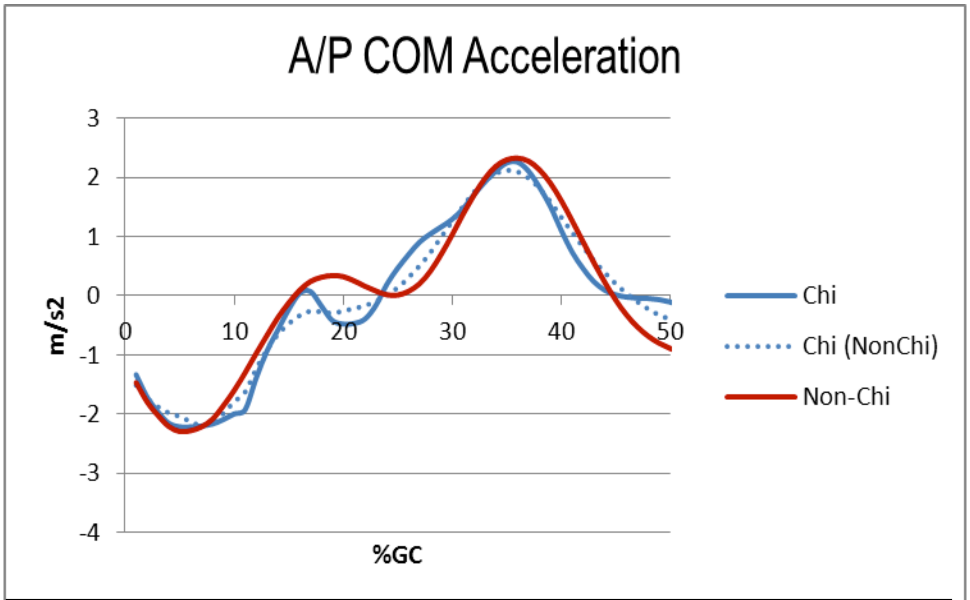

Figure 12: The A/P acceleration of the COM normalized to the entire gait cycle (see terms).

The general pattern of change in velocity of the COM in the anterior posterior direction followed that of the literature for normal running. All runners evidenced both positive and negative acceleration, during the propulsion and braking phases of the gait cycle respectively. Our results indicated that Chi runners in both conditions had similar COM acceleration in the A/P direction.

3.1c: "Lean" angle

The angle of lean was analyzed to determine whether this factor varied between the different groups. The results from this study indicate that there was no significant difference in the lean angle between conditions. The Chi runners had a stance angle of 86.6 degrees calculated from the horizontal and the regular running group had an average of 86.13 degrees. The Chi runners in the non-Chi condition demonstrated a slightly larger angle; however the difference was only tenths of a degree, indicating that the angle of lean was not significantly different (p=.467).

Condition	**Average and standard deviation**

Chi	86.6017± 1.23 degrees
Chi (non-Chi)	86.99433± 2.18 degrees
Non-Chi	86.133± 1.92 degrees

Table 3: Lean angle values

3.1d: Gravitational moment at stance

Since gravity is the described by Chi running proponents as the motive force of the runner during Chi running, the goal of this study was to determine how gravity affects the Chi runner. One approach to determining the role of gravity is to determine the gravitational moment about the ankle. This study examined one leg of the runner to determine the gravitational contribution to a forward moment.

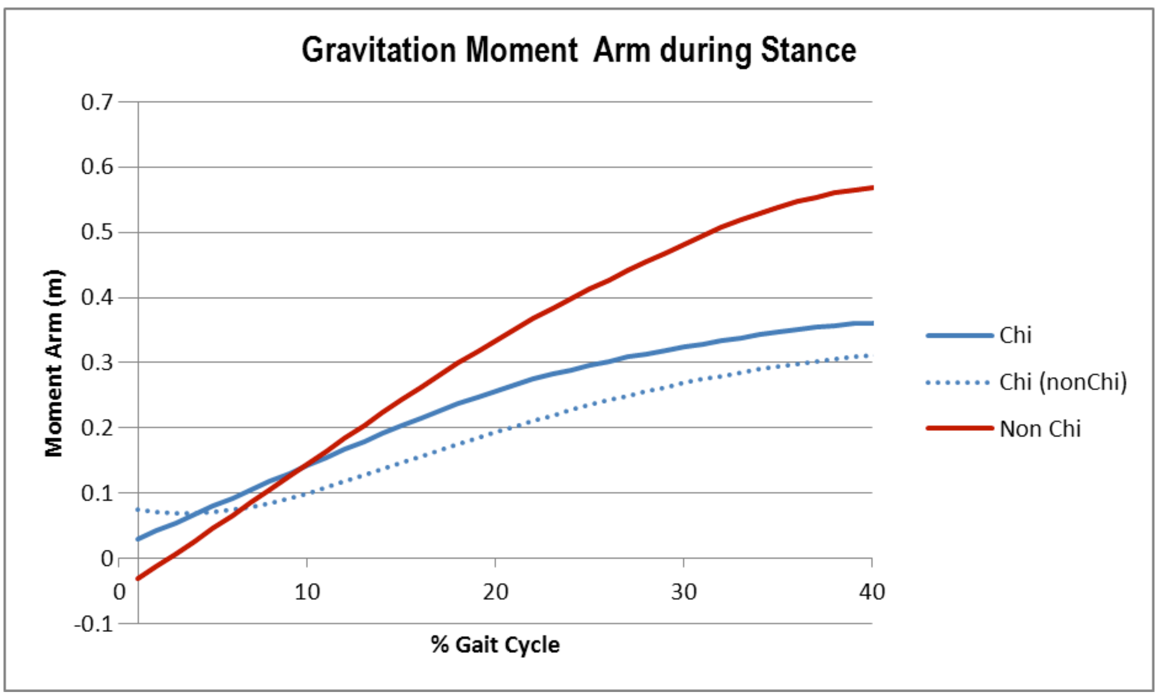

Figure 13: The above figure shows the moment arm for all three groups, Chi (blue), Chi (non-Chi) blue dashed),

Condition	Average and standard deviation
Chi	0.2348m ± 0.127
Chi (non-Chi)	0.1905m ± 0.072
Non Chi	0.3160m ± 0.04

Table 4: moment arm values

The calculated moment was determined by the difference in the y or A/P direction from the ankle to the COM. Each participant's data was normalized for body weight using the following equation; M=mg*d/mg. After normalization, the remaining value (meters) is known as the moment arm (Hof, 1996). The stance moment was actually larger for the participants in the normal running group. This argues against the hypothesis that Chi runners would have a larger gravitational moment about the center of mass. The average moment arm was calculated through the stance phase of the gait cycle. The Chi Runners had an average moment arm of 0.3911 meters whereas the non-Chi group had an average moment arm 0.5987 meters. This difference was not found to be statistically significant (p=0.229). It was found that the Chi group when running non-Chi had a moment of .2417 meters. This result was also not statistically different from the Chi condition (p=.524). This indicates the non-Chi runners' ankle and COM were further apart (y direction) then the ankle and COM of the Chi runners. The Chi runners running non Chi were unable to match the non-Chi group's moment arm. The data also suggest the Chi runners were not able to adopt a "normal," non-Chi stride.

3.2: Electromyography

To determine individual differences in muscle activation, the best approach was to compare the Chi runners in both Chi and non-Chi conditions. This strategy removes inherent individual differences and allows for a more accurate conclusion of changes in muscle activation. The RMS values for each muscle were calculated and normalized to the gait cycle using the left ankle marker. The RMS values are from initial heel contact to initial heel contact or one full stride.

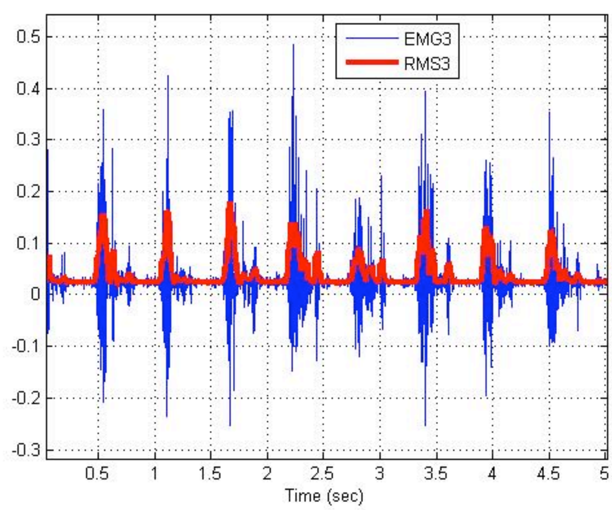

Figure 14: Represents what the raw EMG data (blue) and its RMS (red)

The results for each Chi runner are shown below. Each graph contains the average of the Chi trials and the average of the non-Chi trial per participant. Again, these values are plotted with respect to the percent of step cycle as indicated by kinematic markers beginning with initial contact and extending to the next initial contact of the opposite foot. The RMS value was calculated for the stance phase of the gait cycle to determine the timing and amplitude of the leg muscles while in contact with the ground.

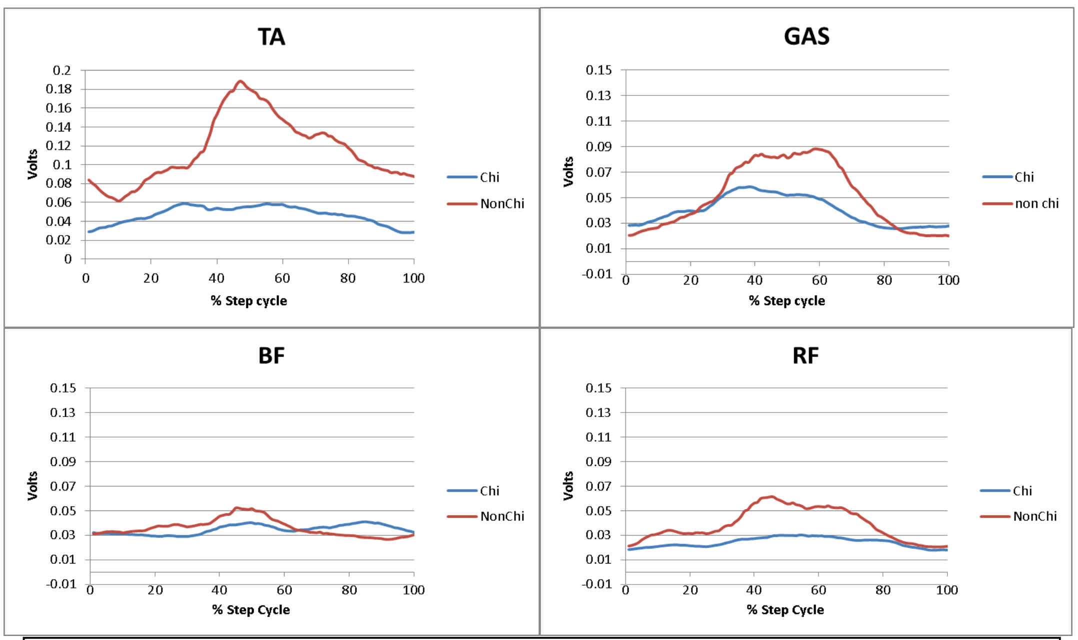

Figure 15: EMG data for Chi and Non-Chi conditions for Chi Participant 1

Chi runner one exhibited definite differences in the amplitude of muscle activation during Chi running and non-Chi running trials. However, the patterns of the muscle activations are very similar in both conditions. The differences between the conditions were not statistically significant.

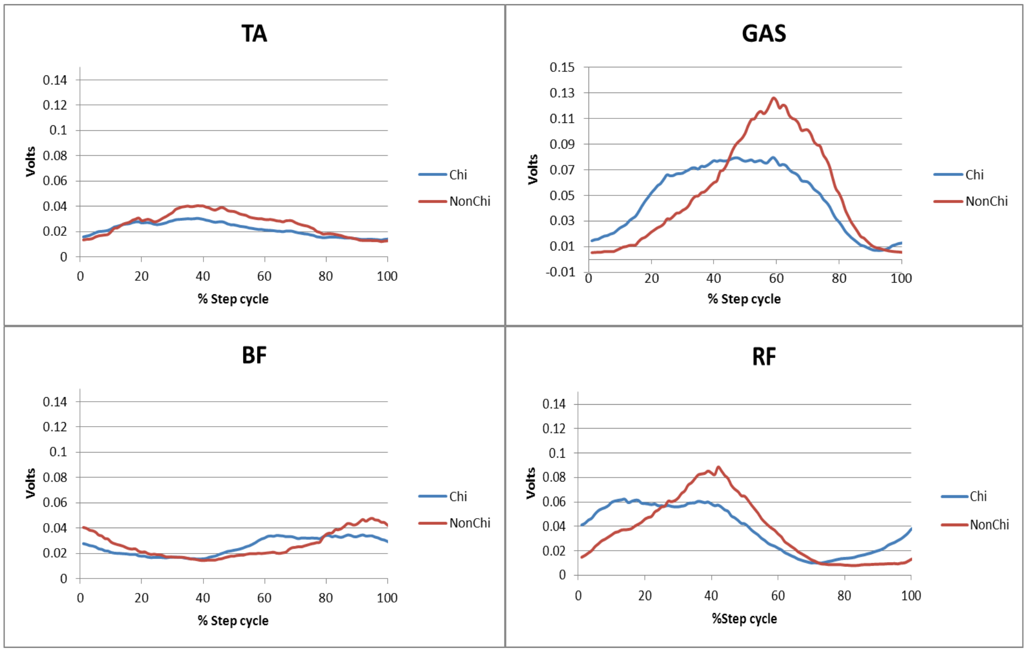

Figure 16: EMG data for Chi and Non-Chi conditions for Chi Participant 2

Chi Runner two showed slight shifts in the timing of muscle activation from Chi to non-Chi trials. These data indicate that the Chi running muscle activation onset occured roughly five percent of the gait cycle prior to the non-Chi trials for three of the four muscles. These slight shifts in muscle sequencing were not significant.

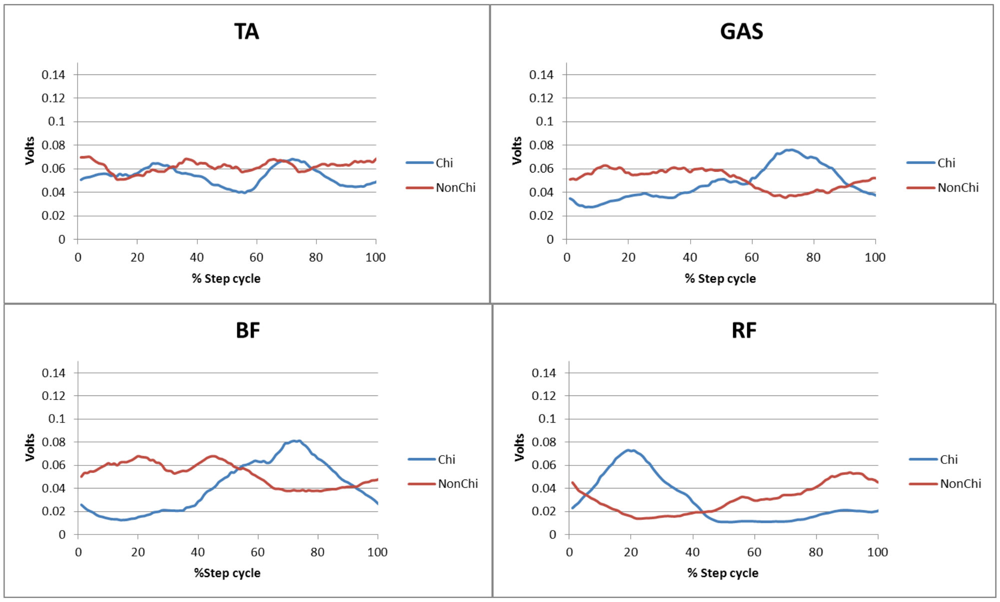

Figure 17: EMG data for Chi and Non-Chi conditions for Chi Participant 3

Data from Chi runner three revealed different activation patterns for Chi and non-Chi trials. This was the only participant to show an obvious change in activation timing. Chi runner three did not show as much difference in EMG amplitude, but the activation pattern was different from those of the other Chi participants.

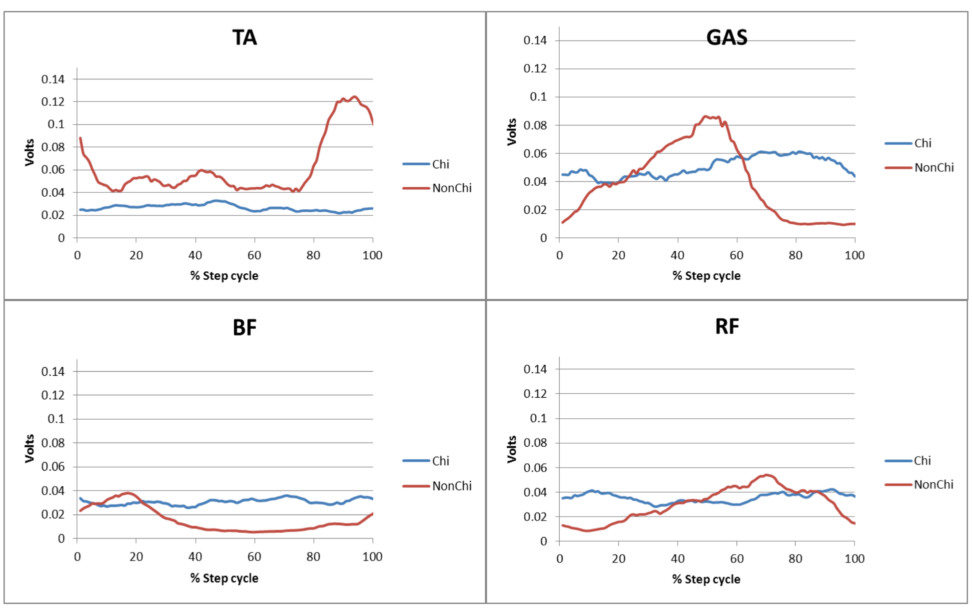

Figure 18: EMG data for Chi and Non-Chi conditions for Chi Participant 4

Data from Chi runner four revealed differences in both the sequencing and the amplitude for all four muscles. This runner had less EMG amplitude for all four muscles in the Chi condition. The differences in timing patterns were irregular and not clearly related to differences in the runner's mechanics between the Chi condition and the non-Chi condition.

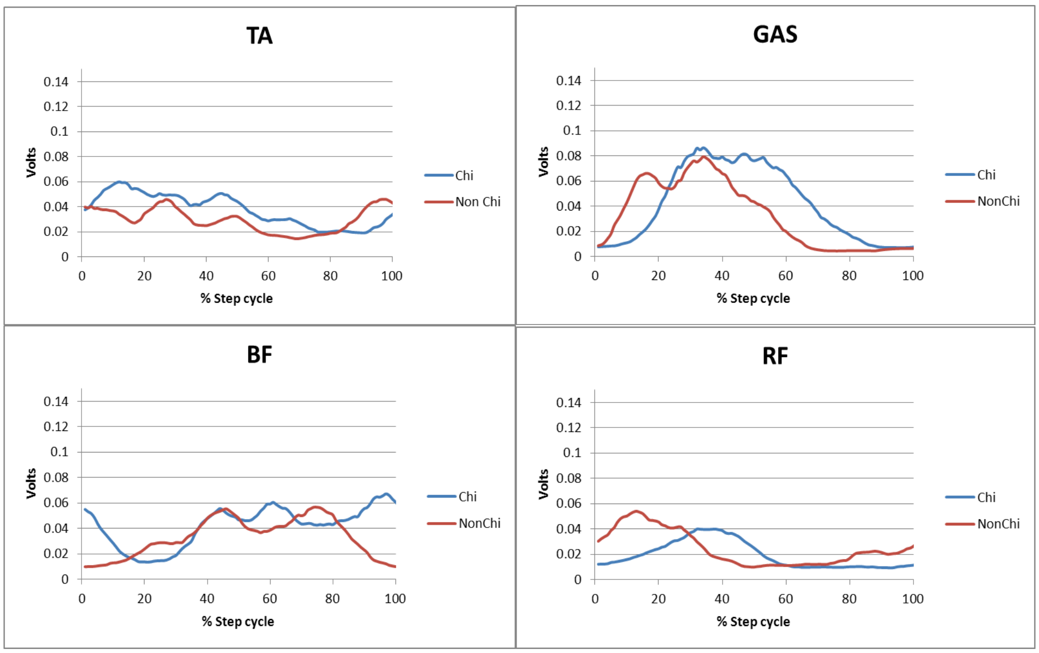

Figure 19: EMG data for Chi and Non-Chi conditions for Chi Participant 5

Chi runner five had similar activation patterns in both the Chi and non-Chi conditions. Chi runner five was the only Chi runner who did not show increases in EMG amplitude from Chi to non-Chi conditions. The non-Chi trials for this particular runner had a slightly lower amplitude than the Chi trials.

Chapter 4: Discussion

4.1 Main Results:

Visual inspection of running mechanics during data collection sessions suggested that there was a noticeable difference in the running form of Chi runners and non-Chi runners. The data calculated for the dependent variables, however, failed to support this observation.

4.1a: Vertical displacement of the COM

The small changes observed in the COM vertical pattern between both groups and conditions were not significant. Since the Chi running technique is based on the idea of ankle lean and “falling” forward, the Chi runner should have demonstrated a smaller vertical excursion of the COM, since they are not actively trying to push down against the ground and are trying consciously to “stay level”. Perhaps this mantra is simply not realistic, since any running involving flight will require a parabolic flight path of the COM. The results showed that the COM vertical displacement for Chi runners was less than that of the regular runners, but also indicated the Chi runners have a lower overall COM position throughout the entire gait cycle. The Chi running technique may affect this position by creating more knee flexion, trunk flexion, and potentially changing arm swing mechanics. The data do not provide evidence related to which of these elements could shift the COM lower, but it does exclude the lower COM position being attributed to anthropometric differences, as the COM is normalized to percent body height.

The non-Chi group exhibited a greater COM vertical displacement on average. This almost certainly is related to the non-Chi runners having a longer flight phase in the gait cycle. This longer flight phase could be due to a slower cadence. The non-Chi runner’s stride could be characterized as a bounding movement, where they are actively pushing backwards and downwards against the ground. This bounding action would explain the greater peak of the COM trajectory. The Chi method teaches runners to reduce this bounding motion by having runners keep their feet underneath their body. The Chi method instructs the runner to stay level and to minimize vertical motion; therefore the flight phase during Chi running should have a shorter duration when compared to non-Chi running.

Two things could have affected the data collection process for the COM calculation. The Chi runners had not often run on treadmills. Efforts were made to account for the lack of treadmill experience by allowing the participant to adapt to the treadmill for as long as necessary. Most participants did not spend more than 10 minutes in the adaptation phase prior to data collection. Also, there are known differences in kinematics collected on a treadmill vs. overground running although they are minimal (Riley, 2008). While significant reduced vertical COM excursion has not been reported, it is possible that this may have been a factor. A point of future research could be to test these two running styles overground.

4.1b: A/P acceleration of the COM

The A/P trajectory of the center of mass moved in an increasingly upward pattern before becoming negative again, much like the literature states (Hinrich et al, 87). The middle figure on the left depicts the A/P force for a midfoot/forefoot strike (Cavanagh, 1977). Although the gait cycle in this study was defined differently, it is clear there is a positive and negative acceleration (i.e.: propulsion and braking.

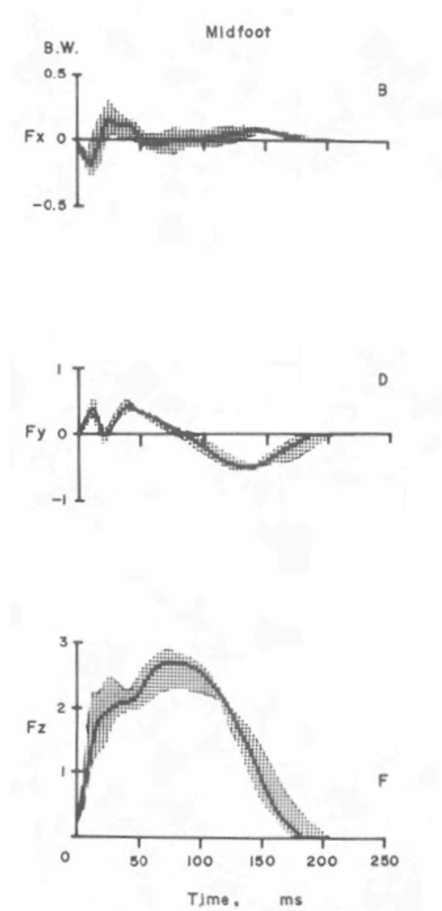

Figure 20: Cavanagh, 1977. GRF in the M/L, A/P and vertical directions.

The results from the current study show the same trends. The area between the positive peak and the negative peak is the flight phase. The Chi and non-Chi group both showed similar patterns for the COM in the A/P direction.

This study determined that the A/P trajectory of the COM was similar for chi runners and regular runners. It was originally hypothesized that the Chi runners would have less braking or backwards acceleration of the COM because they would employ a forefoot strike, reducing the initial impact transient of the ground reaction force. It was also hypothesized that the forward or propulsion component would be smaller due the effect of gravity and the resultant net acceleration per stride would be zero. The data showed no significant differences between the two conditions, indicating that there were only minimal variations in the COM acceleration in the A/P direction.

To calculate the A/P COM acceleration, the second derivative of the position data was computed. Using forward dynamics to calculate the acceleration will magnify noise in the data. The ideal way to collect the COM acceleration would have been to use an instrumented treadmill with an embedded force plate. The Non-Linear Biodynamics Laboratory at the University of Texas does not contain a forceplate treadmill. Although this would have given a cleaner estimate of the COM in the A/P direction, the second derivative of COM position is still a fair measure of COM acceleration.

Both groups and conditions were calculated in the same manner; therefore any noise should have been constant across trials.

The reasoning behind this lack of significance may again have been the effect of the runners running on a treadmill. With a set speed, the runner is constrained regardless of the form they are using. A participant cannot shift between paces significantly to alter the level of braking and propulsion forces while running at a set speed. A follow up study could test both styles during overground running to determine if there was a significant difference, or they could be tested on a self-paced feedback loop treadmill to determine the amount of net acceleration and documented changes in speed.

4.1c: "Lean" Angle

The purpose of analyzing the angel of lean was to determine if the runner was effectively adopting the Chi running form as prescribed. The Chi method is based on the idea that the runner can create a straight rigid line from the ankle to the center of mass (reference figure 1). The lean is the main principle of Dryer's technique; it is what allows the runners to have gravity "propel" them forward.

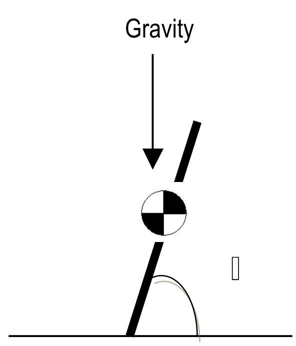

Figure 21: Demonstrate the calculated lean angle

The angle was measured with respect to the vertical axes and then normalized to the horizontal. As expected, all runners showed a lean to a certain extent. According to a compilation of studies in “the biomechanics of distance running,” (Cavanagh, 1990) runners often demonstrate touch down angles of about 80 degrees from the horizontal. Since Chi runners are encouraged to create a larger lean, the data collected failed to support the original hypothesis. Research has shown that barefoot runners have a smaller touchdown angle as shod runners. This is interesting because Chi running requires the runner to strike the ground with the forefoot much like barefoot running. Although, the original hypothesis was that a Chi runner would have a larger angle of lean, it is entirely possible that with a proper forefoot strike the Chi runner may minimize the touchdown angle (Bates et al 1978). Although the data do not provide significant evidence that this in fact is the case, it seems highly reasonable.

The smaller angle of lean indicates that the COM is relatively close to the COP of the base of support (although COP was not measured in this study). Running differs from walking in that it has phases of single leg stance and a phase of complete flight. To maintain balance, or instantaneous static equilibrium at stance, the COM needs to be within the single foot base of support. This will allow the runner to maintain his position and decrease the need for lateral stabilization. Therefore, it is also possible that a runner cannot increase the angle by simple changes in mechanics without creating an unbalanced system.

The treadmill apparatus potentially could have an effect on the acceleration of the runner in both Chi running and non-Chi conditions. The continuously moving belt may have affected the braking phase of the gait cycle by allowing the runner to passively move their foot behind them. There is an offset in the data set caused by an unknown source. Further examination will be performed to determine the root of the bias. The runner should experience zero acceleration during flight.

4.1d: Gravitational moment at stance

Non-Chi runners exhibited a larger moment arm compared to the Chi running group. According to the principles of the Chi technique, the runner uses gravity to propel them forward. When this study was originally designed, it was hypothesized that gravity could cause a larger moment about the ankle according to Dryer's methodology (Dryer &Dryer, 2004). Upon further inspection of the results, the data indicates that non-Chi runners actually have a larger moment arm. This intuitively makes sense. The Chi technique explains that runners want to keep their feet underneath their body and engage in a forefoot strike. These two instructions cause the Chi runner to keep the feet (i.e. the ankle) closer to the body (i.e. the COM), therefore shortening the moment arm. The calculation of the moment arm is the difference in the y or A/P direction from the ankle to the COM. The non-Chi runners were not instructed to run with a certain foot strike, and most likely utilized a rearfoot strike, which 80% of runners commonly use (Novacheck,1998). The moment arm was only calculated for the stance phase, the first 40% of the gait cycle, when the foot is in contact with the ground. The moment is an irrelevant measure when the runner is in flight.

Dryer's gravity theory is based on the law of physics and what he describes is a simple lever system that allows gravity to generate a torque around the ankle causing a horizontal acceleration or "push." In order for this model to function, the legs must be rigid segments. This is not the case in actual human running, where the legs are maximally flexed while in contact with the ground. Dryer's idea could potentially be more realistic during walking since walking is often modeled as an inverted pendulum with rigid segments. This again maybe be fundamentally sound with the laws of physics, but in a biomechanical system, many more variables are introduced (i.e. knees). According to the results, the Chi runners when trying to utilize a non-Chi form were unable to match the data of the non-Chi runners. This indicates the Chi runners have adopted a mechanism that they cannot consciously remove without practice.

4.2: Electromyography

The EMG data in this study showed that muscle activation patterns were similar across both conditions; however there were slight decreases in muscle activation for the majority of participants when Chi running. Two participants showed slight shifts in sequencing patterns for different muscles. The data are inconclusive as to what mechanical changes those particular participants made. Originally, the null hypotheses were accepted for both of the muscle parameters. There were changes in the EMG data but the lack of significance indicates the sample would need to be increase to prove there is actually a difference in the EMG from Chi to non-Chi running. Although muscle sequencing/activation can explain the difference in visual perception of observable differences between Chi and non-Chi forms, it may indicate that the significant differences are found in other variables not selected in this study. Significant changes in kinematic data and other potential muscles groups rather than just the main muscles included in typical gait studies could exist. The Chi runner's mechanics may cause the runner to engage other additional muscles outside of the four muscles analyzed in this study, such as the gluteus maximus. Chi runners often complain about the lack of muscle tone in this region after practicing the form for a prolonged period of time. EMG analysis of the abdominal group could determine whether Chi runners actively recruit their core muscles to affect the prescribed mechanics as well.

In summary, the proponents of the Chi technique state that gravity is the driving force behind the movement. However, these data indicate that the Chi participants are still actively pushing off the ground. Therefore, gravity alone cannot be the motivating force. Conceptually this makes sense, since even a Chi runner will fatigue and tire over time, confirming the muscles are working and producing lactic acid. Further, these data show that runners who have not adopted the Chi running technique are in position to receive larger propulsive impulses from gravity than runners using the Chi technique.

4.3: Limitations

The experimental design of this study was difficult to create because there are not many studies on the specific running form. Much time and effort was dedicated to combining standard concepts from normal running to the Chi method and determining how these are inherently different. Like any study, there are limitations to what the study can cover. An intervention study would have been the ideal way to address differences in running form, and a repeated measures statistical analysis would provide the most accurate results since we could compare individuals to themselves rather then utilizing a control group. In this study, a repeated measures design and a comparison group were used since Chi runners were not expected to be able to recreate their normal stride without influence from the Chi running method.

Another limitation is that the lab where the research wasl collected did not have an instrumented treadmill. An instrumented treadmill would have allowed collection of force plate data as well as kinematic data which would have allowed correlation of kinematic and kinetic data with gait cycle events. Surface electrodes were used to measure EMG signals during running trials. Surface electrodes are a good, non-invasive way of measuring muscle activity but have greater potential for motion artifact especially during running motions. As the data was processed, the EMG signals were inspected for any large variances due to motion artifact.

Another limitation of this study was sample size. Since Chi running is a new technique and participants were only recruited from the greater Austin area, the number of possible participants was limited. This study would have been better with a more expansive demographic and a larger sample size.

Delimitations

This particular study examined a very specific group of runners. Although millions of people run worldwide, only a small percentage of those runners utilize the Chi method of running and will benefit from the outcome of this study. Had significant results been obtained, principles from the Chi technique could be generalized to the greater running community and implemented in training programs. In order to obtain scientific support for the running community to implement Chi running into training programs nationwide, a larger study should be completed.

4.4 Future Directions

Although this study did not reveal statistical significance in any of the examined parameters, we conclude that there were some indications of differences between “normal” running mechanics and Chi running mechanics. As a result of these data, there is reason to explore other parameters to determine possible changes in mechanics of the Chi runner. The theory of gravitational propulsion (Dryer & Dryer, 2004) was not fully addressed by this study due to the inability to collect GRF of the Chi and non-Chi runners. In order to determine the full effect that gravity has on the runner, it would be necessary to repeat this study with a force plate and also to examine both running forms in reduced gravity situations. The lack of statistical significance is most likely attributable at least in part to the small sample size. Follow up studies should be able to confirm differences in mechanics and hopefully provide better insight into the mechanisms underlying the popularity and success of this technique.

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VITA

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